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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

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Electrical converter for converting electrical power

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Electrical converter for converting electrical power

FIELD AND BACKGROUND OF THE INVENTION

The invention relates to an electrical converter for converting electrical power.

In the art of electronic power supplies electrical converters are generally known which store and release electrical energy from supplied electrical power. Such converters usually operate by using an electronic switch to pass a current through an inductor and then interrupt the current periodically to produce a "flyback" voltage for transfer through a diode to a capacitive load. These converters are for example used in battery powered equipment, such as portable communication receivers. In such equipment, the battery usually has to be connected to an AC power supply of 110 V or 220 V whereas the battery has to be charged with a 1.5 V DC-current.

From United States patent publication 5 864 225, a DC-DC dual adjustable voltage regulator is known. The adjustable voltage regulator comprises a field effect transistor operated as a switch connected in series to a diode. At the node between the field effect transistor and the diode a contact of an inductor is connected. Another contact of the inductor is connected in series to a supply voltage output via a resistor. The gate of the field effect transistor is connected to a switching regulator circuit which controls the voltage of the gate and thus the switching of the field effect transistor. Thus, the switching regulator circuit also controls the storing and releasing of energy in the adjustable voltage regulator. The switching regulator circuit has a fixed on-time, variable off-time circuit which controls the switching of the field effect transistor via a buffer circuit. The off-time of the fixed on-time, variable off-time circuit is controlled via a feedback control circuit which controls an oscillator circuit in the fixed on-time variable off-time circuit based on both the output load current and the voltage at the outputs of the adjustable voltage regulator circuit. Hence, the on-time of the adjustable voltage regulator circuit is fixed, while the off-time is varied depending on the output load current and output voltage. The operating of the adjustable voltage regulator circuit thus depends on the output load current and output voltage.

A disadvantage of the circuit known from said US patent publication is that the operation of the adjustable voltage regulator circuit depends on the load connected to the outputs because the output load current and the output voltage are used in the feedback to

determine the variable off-time. A further disadvantage is that this known circuit requires a complex feedback circuit since both the output load current and the output voltage are fedback.

SUMMARY OF THE INVENTION

It is a general object of the invention to provide an improved electrical converter and more specifically an electrical converter which outputs a current which is independent from the output voltage of the converter. The invention therefore provides an electrical converter according to claim 1.

The average current during the primary stroke period and the secondary stroke period is determined because the first time control device limits the current during the primary stroke period and the secondary stroke period to be equal or below the predetermined maximum current. The second time control device controls the duration of the off-time period and thus the average current during a switching period is determined. Thus, the time control devices control the periods based only on the current flowing through the electrical energy storage device. Hence, the average converter current is not dependent on the output voltage of the converter.

The invention further provides an electric appliance according to claim 11. In such an appliance the average converter current is not dependent on the output voltage of the converter device.

Specific embodiments of the invention are set forth in the dependent claims. Further details, aspects and embodiments of the invention will be described, by way of example only, with reference to the Figures in the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 schematically shows a circuit diagram of an example of an electrical converter according to the invention.

Figs. 2A-B shows schematically a graph of currents and voltages in different parts of the converter according to the invention of Fig. 1 as a function of time.

Fig. 3 shows a circuit diagram of an example of a switch control device suitable for the example of an ~~electrical converter according~~ to the invention of Fig. 1.

Figs. 4-6 schematically show circuit-diagrams of examples of voltage to current converters suitable for the example of a switch control device of Fig. 3.

Figs. 7 schematically shows a circuit diagram of another example of electrical converter according to the invention.

Fig. 8 shows an example of an electric appliance comprising an electrical converter according to the invention.

DETAILED DESCRIPTION

The example of an electrical converter 1 according to the invention shown in Fig. 1 is a Discontinuous Current Mode (DCM) converter. DCM converters are generally known in the art. The converter 1 is a down-converter with converter inputs IN1,IN2 for receiving electrical power, such as a DC voltage, and converter outputs OUT1,OUT2 for outputting converted electrical power, for example a DC current or a DC voltage. In this example, the converter outputs OUT1,OUT2 are current outputs. The converter outputs OUT1,OUT2 are connected to a battery 7 which operates at a different voltage than the voltage applied at the converter inputs IN1,IN2. However, other types of devices may likewise be connected to the converter outputs instead of the battery 7.

The converter 1 has an electrical energy storage device 2 for alternately storing and releasing electrical energy from the received electrical power. In this example, the electrical energy storage device is an inductor 2, which can store electrical energy in an electro-magnetic field and release electrical energy by reducing the energy in the electro-magnetic field.

In Fig. 1, the inductor 2 is connected in series with a resistor 5 and a switch 3 to the input IN1. A one-direction conducting device, e.g. a diode 6, connects the second input IN2 to the inductor 2, at the node 32 between the switch 3 and the inductor 2. The diode 6 has a forward direction from the input IN2 to the inductor and a reverse direction from the inductor 2 to the input IN2. Thus, a current can flow through the diode 6 in the forward direction from the input node IN2 through the inductor 2 to the output node OUT1 and substantially no current can flow in the reverse direction towards the input node IN2 or the output node OUT2. Other types one-direction conducting devices may likewise be used instead of a diode. For example a synchronous rectifier field effect transistor may be used which is opened and closed in response to the direction of the current or other devices.

The switch 3 has a first switch contact electrically connected to the converter input IN1, in this example via the resistor 5. The switch 3 further has a second switch contact which is electrically connected to the electrical energy storage device, e.g. the inductor 2. The first switch contact is electrically connected to the second switch contact in a conducting state

of the switch 3. In this conducting state the switch is said to be closed. Thus the switch 3 enables in the conducting state electrical contact between the storage input and the converter inputs IN1,IN2. In the conducting state a current can flow from the input node IN1 to the output node OUT1 via the resistor 5, the switch 3 and the inductor 2 and in this state electrical energy is stored in the inductor 2. In a non-conducting state of the switch 3, the first switch contact is electrically disconnected from the second switch contact. In this non-conducting state the switch is said to be open. Thus, in the non-conducting state, the electrical contract between the inductor 2 and the converter input IN1 is interrupted.

In the non-conducting state substantially no current flows from the input node IN1. However, in the non-conducting state a current can flow from the input node IN2 to the output node OUT1 via the diode 6 and the inductor 2 and electrical energy can be released by the inductor 2 towards the output OUT1. In use, the switch 3 is switched from the conducting state to the non-conducting state and vice versa by a switch control device 4 and thus energy is alternately stored in the inductor and released. Thereby the average current and/or voltage of the electrical power at the converter outputs can be controlled and hence the power be converted.

In Fig. 2A successive stages of the process of storing and releasing energy are illustrated by the solid line I_2 which represents the amount of current flowing from the inductor 2 to the output OUT1, as a function of time t. As shown in Fig. 2A, if the switch 3 is in the conducting state, current flows from the input IN1 to the output OUT1 through the inductor 2 and energy is stored in the inductor during a time called the primary stroke period t_{prim}. The more energy is stored in the electro-magnetic field of the inductor, the less power will be taken from the current and hence the more current flows through the inductor. In the primary stroke energy is released by the inductor 2 as well via the current to the converter output OUT1, however as a net result the energy stored in the inductor 2 increases during the primary stroke t_{prim}.

At a certain moment the switch 3 is switched into the non-conducting state. Thereby, no power is supplied to the inductor 2 anymore and energy is released from the inductor 2 as a current during a time period called the secondary stroke t_{sec}. The primary stroke t_{prim} and the secondary stroke t_{sec} together are also referred to as the on-time t_{on} of the converter 1. In the example of Fig. 1, the control device 4 switches the switch 3 to the non-conducting state when the current through the inductor 2 has reached a predetermined maximum. The predetermined maximum may be any maximum suitable for the specific implementation and may have a constant value or have a variable value, e.g. be

predetermined by some algorithm. Likewise, the predetermined maximum may be fixed or be adjustable. To compensate for delays in the electrical converter, the control device 4 may start switching the switch 3 before the current actually reaches the predetermined maximum, for example by calculating an expected moment at which the current through the inductor will reach the predetermined maximum and switching the switch 3 such that at the expected moment the switch 3 is non-conducting.

After the inductor 2 has released substantially all of the stored energy substantially no current will flow from the inductor 2 to the output OUT1. This interval following the secondary stroke in which substantially no current flows is called the off-time t_{off}. In the off-time t_{off}, the switch 3 is still in the non-conducting state. The primary stroke t_{prim}, secondary stroke t_{sec} and off-time t_{off} together are called a conversion period T, which is also referred to as a switching period T. In Fig. 2A three conversion periods are shown. After the off-time t_{off}, the switch 3 is be turned back to the conducting state and the cycle of storing and releasing energy can be performed again. In the example of Fig. 1, the off-time t_{off} is ended when the average current flowing through the inductor has reached a predetermined value. The average is taken over one conversion period T.

The average current through the inductor 2 during the primary and secondary strokes is determined by the maximum current. In general, the current increases exponentially during the primary stroke and decreases exponentially during the secondary stroke because of the resistor 5 and the inductor 2. In this example the resistor 5 has a small resistance and the current has an approximately linear behaviour as a function of time. The average current during the on time t_{on} is thus approximately equal to half the predetermined maximum current. Thus, by varying the off-time t_{off}, the average current of a conversion period can be controlled. In a mathematical way :

$$I_{average}= I_{max}*(t_{prim}+t_{sec})/(2*T) \qquad (1)$$

In this equation (1) $I_{average}$ represents the average current and I_{max} the predetermined maximum current. Thus, by varying the conversion period T via control of the duration of the off-time t_{off}, the average current during a conversion period can be controlled. Hence, when the predetermined value is a factor alpha times the maximum current I_{max}, the off-time t_{off} is controlled to be:

$$t_{off}=(1\text{-alpha})(t_{prim}+t_{sec})/\text{alpha} \qquad (2)$$

It should be noted that in this example the current through the inductor 2 during the primary stroke and the secondary stroke is substantially linear as a function of on

time. However, in a converter according to the invention the current may behave differently, e.g be quadratic or otherwise as a function of time.

In the example of Fig. 1, the resistor 5 is a current sensing device which senses the current flowing from the input node IN1 through the inductor 2 to the output OUT1, because the voltage V_5 over the resistor 5 is equal to this current times the resistance of the resistor 5. In general this current has a maximum value in the range of 1-10 amperes and the resistor 5 may have any resistance suitable for the specific implementation. To reduce power losses in the converter, the resistance should be as low as possible and for example be in the range of 10-100 milli Ohms. Such resistance results in a voltage drop over the resistor 5 in the range of 0,01 to 1 V, which can be measured easily. However, the current flowing through the inductor 2, the resistance of the resistor 5 and the voltage drop over the resistor 5 may likewise have any other value suitable for the specific implementation.

In the example of Fig. 1, the current sensing device and the switch 3 are implemented as separate devices, i.e. the resistor 5 and the switch 3. However, the current sensing device and the switch 3 may likewise be a single device, such as for example a sensing field effect transistor also known in the art as a sensefet. In general, a sensefet can sense a current flowing through the source and drain and be switched in a conducting state and a non-conducting state. Thus, a sensfet connected between the input node IN1 and the inductor 2 may perform the current sensing function and as well as a switch function.

In the example of Fig. 1, the current sensing device, e.g. the resistor 5, further limits the current flowing to the inductor 2 to a maximum. The resistor 5 thus acts as a limiter in the conducting state of the switch 3. However, when the switch 3 is in the non-conducting state, e.g. during the secondary stroke and in the off-time, the resistor 5 does not limit the current since no current flows through the resistor 5. Hence, in the secondary stroke and the off-time the resistor 5 does not dissipate energy released from the inductor 2 to the converter output OUT1. The maximum current through the resistor 5 may, for example, be equal to the predetermined maximum current I_{max} which triggers the switching of the switch 3 and thus the end of the primary stroke t_{prim} and the start of the secondary stroke t_{sec}.

As shown in Fig. 2A the current flowing through the inductor 2 increases during the storing of energy in the electro-magnetic field, e.g. during the primary stroke t_{prim}, as more energy is stored in the inductor 2. The saturation current is the current flowing through the inductor 2 when no more further energy can be stored in the inductor 2. The maximum current allowed by the resistor 5 or the control device 4 can for example be set to be lower than or equal to the saturation current of the inductor 2 by setting the predetermined

maximum current I_{max} lower than the saturation current and thereby switching the switch 3 automatically before the inductor 2 is saturated. Thereby the inductor 2 is automatically protected against saturation. As will be shown in more detail in Figs. 3 and 4, in the example of Fig. 1 the desired average current is obtained automatically via the control device 4. In this example the control device 4 is a switch control device which switches the switch 3 such that with a suitable on-time and off-time t_{off} of the converter 1, the average current equals the predetermined value. In general, the switch control device 4 can be implemented in any manner suitable for the specific implementation to control the state of an electrical converter device according to the invention. Fig. 3 shows an example of a switch control device 4 for automatic switching which may be used in the example of a electrical converter 1 of Fig. 1. It should be noted that the switch 3 may likewise be switched in a different manner. The control device 4 may for example comprise a suitably programmed microprocessor which measures the maximum current during the primary stroke and the secondary stroke and calculates an off-time period suitable to achieve the predetermined average current and switches the switch 3 accordingly or otherwise.

The switch control device 4 in Fig. 3 opens the switch 3 after a comparison of a first signal V_5 with a reference signal V_{ref} yields a result which satisfies an opening criterion. In this example, the switch control device 4 has a first time control device comprising a comparator 44 which can measure the current through the resistor 5 and compare the measured current with a reference value, in this example by measuring the voltage V_5 over the resistor 5 and comparing the voltage V_5 with a reference voltage V_{ref}. When the voltage V_5 comes above the reference voltage V_{ref}, the control device 4 opens switch 3 and the primary stroke t_{prim} is ended. Thereby, the peak current I_{peak} through the inductor 2 and the desired average amount of current can easily be adjusted by changing the criterion which causes the first time control device to open the switch 3, for example by adapting the reference voltage V_{ref}.

The switch control device 4 compares a second signal with a reference signal V_{tr} and closes the switch 3 if the result of the comparison satisfies an closing criterion. For this purpose, the switch control device 4 has a second time control device 40 with a second comparator device 43 which compares the voltage V_{431} at node 431 with a trigger voltage V_{tr}. When the voltage V_{431} comes above the trigger voltage V_{tr}, the switch control device 4 closes switch 3 and thus the primary stroke is started. Thereby, the average current $I_{average}$ through the inductor 2 can easily be adjusted. The average current $I_{average}$ can for example be changed via the manner in which the second signal is generated, for example by changing the factor

alpha in the first on-off period control device 41 as will be explained below in more detail or otherwise.

In the example of Fig. 3, the switch control device 4 has a first on-off period control device 41. The first on-off period control device 41 has a first capacitor, from hereon referred to as an integrating capacitor 413, a first current source 412 and a switch 414 which are connected to each other and form an interruptable current loop. The switch 414 acts as an interrupter and can open and close the interruptable current loop. At one node of the integrating capacitor 413 the interruptable current loop is connected to a second current source 411. Thus, when the switch 414 holds the loop open, no current can flow through the loop and current can only flow from the second current source 411 to the node of the integrating capacitor 413 connected to the second current source 411. In the open loop state, the integrating capacitor 413 is charged and hence the voltage over the integrating capacitor 413 is increased. When the loop is closed by the switch 414, current can flow through the loop. Thus, the integrating capacitor 413 will discharge and the voltage over the integrating capacitor 413 will be decreased.

In the example of Fig. 3, the loop of the first on-off period control device 41 is closed during the primary and secondary stroke and the loop is open during the off-time t_{off}. Thus, during the primary stroke t_{prim} and the secondary stroke t_{sec}, the switch 414 is closed or in the conducting state and in the off-time t_{off} the switch 414 is open or in the non-conducting state. Hence, the voltage V_{413} decreases during the primary stroke t_{prim} and the secondary stroke t_{sec} and increases during the off-time t_{off}. The current to the integrating capacitor 413 is depicted in Fig. 2A with dashed line I_{413}. The voltage over the integrating capacitor 413 is depicted in Fig. 2B as a function of time with dashed line V_{413}. As shown in Fig. 2B, the voltage over the integrating capacitor 413 alternately increases and decreases around a DC off-set level V_{DC}.

In the example shown, the first current source 412 delivers a current Iref in the direction indicated and the second current source 411 is set to deliver a current Iref*alpha, alpha being a factor smaller than 1, in the direction indicated with the arrow. Hence, in the closed loop state the voltage V_{413} over the integrating capacitor 413 can be described as $V_{413}= V_0 -((1-alpha)*Iref*t_{closed})/C_{413}$, with C_{413} representing the capacitance of the integrating capacitor 413; V_0 the voltage over the integrating capacitor 413 at the moment the loop was closed and t_{closed} the time lapsed after closing the loop.

When the loop is opened, the voltage over the integrating capacitor 413 can be described as $V_{413}=V_0+(alpha*I_{ref}*t_{open})/C_{413}$, with t_{open} representing the time passed after

opening the loop with the switch 414 and V_0 the voltage over the integrating capacitor 413 at the moment the loop was opened. The open time t_{open} is equal to the off-time of the converter 1 and the closed time t_{closed} is equal to the on-time t_{on} of the converter 1. Thus, if the voltage over the integrating capacitor 413 is used as the second signal V_{431} and the trigger voltage V_{tr} is set to V_0, the switch 3 is closed, e.g. the primary stroke t_{prim} is started when the off-time has equalled (1-alpha)(t_{prim}+t_{sec})/alpha and the average current has the predetermined value.

The average current of a converter according to the invention with a control device comprising a first on-off period control device 41 as depicted in Fig. 3 can be adjusted easily by changing the ratio alpha of the currents of the current sources 411,412. For example, the average current from the second current source 411 to the integrating capacitor 413 (and thus the constant alpha) can be controlled by alternately enabling and disabling the current flow from the second current source 411. The average current from the second current source 411 to the integrating capacitor 413 is then equal to the alpha times Iref times the duty cycle of the enabling and disabling. The current from the second current source 411 will then have a frequency of the enabling and disabling. However this frequency component is eliminated by the integrating properties of the integrating capacitor 413. With alternately enabling and disabling of the current from the second current source 411 to the integrating capacitor 413, the average converter current is linear dependent on the duty cycle and thus via control of the duty cycle a linear control of the average current is obtained. The enabling and disabling may for example be implemented by providing a switch between the second current source 411 and the integrating capacitor 413 of the switch and alternately opening and closing the switch via suitable switch control means.

The current of the converter may likewise be controlled via the voltage over the integrating capacitor 413. For example, a field effect transistor may be connected with the source and drain to the respective electrodes of the integrating capacitor 413. By applying a suitable voltage to the gate of the field effect transistor, a current can flow via the field effect transistors between the electrodes of the integrating capacitor 413 whereby the integrating capacitor 413 is discharged and the voltage over the integrating capacitor 413 changed.

The first on-off period control device 41 and optionally the second on-off period control device 42 are simple and use few components. Furthermore, the first on-time control device 41 forms a first order integrating control loop with the on-time t_{on} as input and the off-time t_{off} as output. Thus, the switch control device 4 does not use a feedback loop and hence does not have stability problems caused by the feedback.

In the example of Fig. 3, the integrating capacitor 413 is connected to a voltage input 415 of a voltage to current converter 421 of a second on-off period control device 42. The voltage to current converter 421 outputs a current I which is a function of the voltage V presented at its input, e.g. in a mathematical notation $I=f(V)$. In Figs 4-6 examples of the voltage to current converter 421 are shown. In the example of Fig. 3, the voltage to current converter 421 is supposed to be implemented as is depicted in Fig. 4.

The current output of the voltage to current converter 421 is connected to a contact of a second capacitor 422. Thereby, the second capacitor 422 is charged with the current from the current output, in response to the voltage V_{413} over the integrating capacitor 413. Thus, the amount of current fed to the second capacitor 422 and hence the voltage V_{422} over the contacts of the second capacitor 422 depends on the voltage V_{413} over the integrating capacitor 413 and hence on the factor alpha. Thereby, the off-time depends on the factor alpha as well. Furthermore, the converter can be soft started via the voltage to current converter 421 and the integrating capacitor 413. Initially, only a low voltage will be present over the integrating capacitor 413 which voltage will increase after some switching. After several periods, the voltage over the integrating capacitor 413 will have a DC-offset V_{DC} as shown in Fig. 2B. When the voltage over the integrating capacitor 413 is low, only a small current will be outputted by the voltage to current converter 421 and hence, the second capacitor 422 will be charged relatively slowly and it will take a relative long time until the voltage over the second capacitor 422 reaches the trigger voltage V_{tr}. Thus, using a suitable capacitance for the integrating capacitor 413, the time for charging the second capacitor 422 to V_{ref} will take a relatively long time and the amount of power provided at the converter output OUT1 can initially set to be low and then be increased over time. The time for charging and discharging can also adjusted via the constant alpha of the second current source 411.

The second on-off period control device 42 is connected to an input of the second comparator 43. In Fig. 2B the line V_{422} represents the voltage at the positive input 431 as a function of time. In Fig. 2B the trigger voltage V_{tr} is indicated with the dotted line V_{tr}. The second capacitor 422 is connected to a switch 423 and forms a current loop with this switch 423. The switch 423 can open and close the loop. At one node of the second capacitor 423 the loop is connected to the positive input 431 of the second comparator 43. Thus, the voltage V_{422} over the second capacitor 422 is transmitted to the second comparator 43. The switch 423 is switched depending on the current flowing through the inductor 2 of the

converter of Fig. 1 and is opened at the moment the current through the inductor 2 reaches the maximum current, as is shown with the dashed line I_{max} in Fig. 2A.

In the example of Fig. 3, the switch 423 is closed, that is the switch 423 is switched into the conducting state, when the primary stroke t_{prim} is started, Thus at the start of the primary stroke t_{prim}, the second capacitor 422 is short circuited and discharged, as is depicted in Fig. 2B with the solid lineV_{422}.Thereby a too short time period of the primary stroke t_{prim} is prevented, which is especially useful if the amount of output current at the converter output OUT1,OUT2 has to be controlled with high precision.

In the example of fig. 3, the switch 423 is kept closed during the entire primary stroke t_{prim}, however it is likewise possible to close the switch 423 for a short period only at the start of the primary stroke t_{prim}, e.g. in a pulsed manner. It is also possible to keep switch 423 closed in dependence on the voltage over the second capacitor 422, e.g. until the voltage over the second capacitor 422 is substantially zero.

The voltage to current converter 421 can for example be implemented as shown in Fig. 4, but can also be implemented in a different manner for example as depicted in Figs. 5 and 6 or otherwise. In general, the voltage to current converter 421 may be implemented in any manner suitable for the specific application.

In the voltage to current converter 421 of Fig. 4, the output of a amplifier 4211 is connected to the base of a bipolar transistor 4224. The inverting input of the amplifier 4211 is connected to the emitter of the bipolar transistor 4224. The emitter is further connected to ground gnd via a resistor 4222. The collector of the bipolar transistor 4224 is connected to an input a current mirror 4223 which at an output outputs a current which is proportional to the current drawn from the current mirror 4223 by the bipolar transistor 4224, and these currents have a ratio of A:1. Thus, the current at the output of the current mirror 4223, is linear dependent on the voltage applied at the non-inverting input of the amplifier 4211.

In the example of Fig. 5, a bipolar transistor 4225 is connected with its base to the first time control device. The collector of the bipolar transistor is connected to a current mirror and the emitter to ground. Thus, the current at the output of the current mirror 4223 is exponentially dependent on the voltage applied at the base of the transistor.

In Fig. 6, the gate of a field effect transistor 4226 is connected to the first time control device 41. The source is connected to ground and the drain to the current mirror. Thus the current at the output of the current mirror 4223 is more or less quadratic dependent on the control voltage applied at the gate of the field effect transistor 4226.

The switching of a converter according to the invention depends only on the current flowing through the electrical energy storage device. Hence, the switching is substantially independent from the input voltage or the output voltage of the converter, as well as the inductance of the inductor 2. The output current of a converter according to the invention is therefore also independent from the input voltage or the output voltage of the converter, as well as the inductance of the inductor 2.

The example of a switch control device 4 of Figs. 3 and 4 has an inherent stability because no feedback is present and the off-time is controlled in a feedforward manner. Hence no additional measures are required to stabilise an electrical converter according to the invention. Furthermore, when a second on-off period control device 42 is used, the capacitor 413 in the first on-off period control device 41 is not critical to the functioning of an electrical converter according to the invention. As long as the voltage over the integrating capacitor 413 is not clipped, the desired average current will be obtained via the current balance in the on-off period control devices 41,42. Furthermore, subharmonic changes, for example caused by irregular changes in t_{off}, do not significantly disturb the average current because of the current balance. However, in an electrical converter according to the invention, the switch control device 4 may likewise have only a first on-off period control device and no second on-off period control device.

Figs. 7 shows another example of an electrical converter circuit according to the invention. In the example of Fig. 7, substantially no current flows through the battery during the primary stroke because the inductor is connected in a loop with the diode and battery, while the node between inductor and diode is connected via a switch to an input and the node between diode and battery is connected to the other input. In the example of Fig. 7, the switch may be controlled by a control circuit similar to the example of Fig. 3. However, the average current flowing through the inductor 2 to the battery during one conversion period is equal $(½*I_{peak}*t_{sec})/T$ instead of $½*I_{max}*(t_{prim}+t_{sec})/T$ and by switching for example switch 413 at t_{sec} instead of t_{on}, the average current can be controlled via the off-time t_{off} as well.

The converter outputs OUT1,OUT2 of the examples of an electrical converter according to the invention of Figs. 1 and 6 are current outputs. However an electrical converter according to the invention may likewise have converter outputs which are voltage outputs. For example the converter outputs OUT1,OUT2 of the example of an electrical converter 1 in Fig.1 may be connected to an output voltage control circuit which senses the output voltage at the converter outputs and adjusts the current outputted at the converter

outputs to maintain a specific output voltage. The output voltage control circuit may for example adjust the constant alpha of the second current source 411 in the switch control device 4 of Fig. 1 via suitable means, such as the duty cycle of a switch as is explained above in more detail.

The electrical converter in accordance with the invention is suitable for a variety of apparatuses with rechargeable batteries that are charged from the mains voltage in particular rechargeable electrical shavers and toothbrushes. Fig. 8 shows by way of example a shaver SVR with a motor M which drives shaving heads SH. The motor M is engaged with a switch SW, which connects the motor M to the rechargeable battery B, which together with the other electronic components, for example those of the circuits shown in the Figures 1 and 3, is accommodated on a printed circuit board PCB in the shaver SVR. Figure 8 further shows a power supply unit PSU, which may contain parts of the electrical converter device. The power supply unit PSU has an integrated mains plug PLG for connection to the mains voltage and a connecting cord CRD, which can be coupled to an inlet (not shown) of the shaver SVR by means of an outlet OTL.

CLAIMS:

1. An electrical converter (1) comprising:

- at least one converter input (IN1,IN2) for receiving electrical power;
- at least one converter output (OUT1,OUT2) for releasing electrical power;
- an electrical energy storage device (2) having a storage input connected to at least one of the converter inputs (IN1,IN2) and having a storage output connected to at least one of the converter outputs (OUT1,OUT2), for storing during a primary stroke period (t_{prim}) electrical energy from the received electrical power and for releasing during a secondary stroke period (t_{sec}) electrical energy to the converter output (OUT1,OUT2),

said electrical converter (1) further comprising a control device (4) comprising:

- a current sensor (5) for sensing the amount of current flowing to the electrical energy storage device (2);
- a first time control device (44) communicatively connected to the current sensing device, for controlling the duration of at least one of said stroke periods such that the current flowing to the electrical energy storage device (2) during said stroke periods is substantially equal or lower than a predetermined maximum current (I_{max}); and
- a second time control device (40) for controlling the duration of an off-time period (t_{off}) in which the electrical energy storage device (2) releases substantially no electrical energy, such that a time-average of the current flowing to the electrical energy storage device (2) is equal to a predetermined value, which time-average is the average during a switching period comprising the primary stroke period (t_{prim}), the secondary stroke period (t_{sec}) and the off-time period (t_{off}).

2. An electrical converter (1) as claimed in claim 1, wherein the first time control device (44) comprises means for ending the primary stroke period (t_{prim}) when the current flowing to the electrical energy storage device (2) is equal to the predetermined maximum current (I_{max}).

3. An electrical converter (1) as claimed in claim 1 or 2, wherein the second time control device (40) comprises means for ending the off-time period (t_{off}) when the average current flowing to the electrical energy storage device (2) during a switching period equals the predetermined value.

4. An electrical converter (1) as claimed in claim 3, wherein said second time control device (40) comprises:
an first on-off period control device (41) for determining an on-time period (t_{on}) corresponding to a desired time of the primary and secondary stroke (t_{prim},t_{sec}) of the electrical energy storage device (2) and an off-period corresponding to a desired off-time period (t_{off}) of the electrical energy storage device (2), which first on-off period control device (41) has an output for outputting an end off-time signal, which output is communicatively connected to a control of the electrical energy storage device (2).

5. An electrical converter (1) as claimed in claim 4, wherein the first on-off period control device (41) comprises:
a first capacitor (413) connected in an interruptable loop (412-414) to a first current source (412),
which interruptable loop (412-414) is further connected to a second current source (411),
an interrupter (414) for interrupting said interruptable loop when the sensed current is equal to the predetermined maximum current (I_{max}) and closing the interruptable loop when the current sensed by the current sensing device is substantially zero.

6. An electrical converter (1) as claimed in claim 4 or 5, wherein the second time control device (40) further comprises:
a second on-off period control device (42) communicatively connected to the output of the first on-off period control device (41), for determining a second off-period corresponding to a desired combined time of the secondary stroke period (t_{sec}) and the off-time period (t_{off}), which second on-off period control device (42) is arranged for generating a start signal (strt t_{prim}) for starting the primary stroke period (t_{prim}) at an end of the second off-period.

7. An electrical converter as claimed in claim 6, wherein the second on-off period control device (42) comprises

a voltage to current converter (421) having a current output, for outputting at the current output a current corresponding to the voltage (V_{413}) over the first capacitor (413), which voltage to current converter (421) is connected to the first capacitor (413),
which second on-off period control device (42) further comprises:
a second capacitor (422) connected with a contact to the current output, which contact is also connected to a comparator device (43) for comparing a capacitor voltage (V_{422}) over the second capacitor (422) with a trigger voltage (V_{tr}) and outputting the start signal if the trigger voltage (V_{tr}) is below the capacitor voltage and
a discharging device (423) for discharging the second capacitor in response to the start signal.

8. An electrical converter (1) as claimed in any one of the preceding claims, further comprising at least one switch (3) for enabling in a conducting state electrical contact between the storage input and the at least one converter input (IN1,IN2) to store electrical energy in the electrical energy storage device (2) and interrupting in a non-conducting state the electrical contact of the electrical energy storage device (2) with the converter input (IN1,IN2) to release electrical energy from the electrical energy storage device (2) to the converter output (OUT1,OUT2), which switch (3) is controlled by said control device (4).

9. An electrical converter (1) as claimed in any one of the preceding claims, wherein the current sensing device (5), the switch (3) and the electrical energy storage device (2) are connected in series between a first converter input (IN1) and a first converter output (OUT1)and a node (32) between the switch (3) and the electrical energy storage device (2) is connected to a second converter input (IN2) with a one-direction conducting device (6).

10. An electrical converter (1) as claimed in any one of the preceding claims, wherein the predetermined maximum current (I_{max}) is lower than or equal to the saturation current of the electrical energy storage device (2).

11. An electric appliance (SVR) comprising: a rechargeable battery (B), an electric motor (M), a switch (SW) for connecting the motor (M) to the battery (B), and an electrical converter device as claimed in any of the preceding claims for charging the battery (B) and/or powering the motor (M).

ABSTRACT:

An electrical converter (1) comprising a converter input (IN1,IN2) for receiving electrical power; a converter output (OUT1,OUT2) for releasing electrical power; an electrical energy storage device (2) having a storage input connected to a converter input (IN1,IN2) and having a storage output connected to a converter output (OUT1,OUT2). During a primary stroke period (t_{prim}) electrical energy is stored from the received electrical power and during a secondary stroke period (t_{sec}) electrical energy is released to the converter output (OUT1,OUT2). The electrical converter (1) has a control device (4) comprising: a current sensing device (5) for sensing the amount of current flowing to the electrical energy storage device (2); a first time control device (44) communicatively connected to the current sensing device, for controlling the duration of at least one of said stroke periods such that the current flowing to the electrical energy storage device (2) during the primary and secondary stroke is substantially equal or lower than a predetermined maximum current; and a second time control device (41-43) for controlling the duration of an off-time period (t_{off}) in which the electrical energy storage device (2) releases substantially no electrical energy, such that a time-average of the current flowing to the electrical energy storage device (2) is equal to a predetermined value, which time-average is the average during a switching period comprising the primary stroke period (t_{prim}), the secondary stroke period (t_{sec}) and the off-time period (t_{off}).

Fig. 1

Request for grant of a European patent

User reference: PHNL030049EPP
System identification: 37634.6820566551
Application No:

0	**For official use only**	
	Application number: MKEY	
	Date of receipt (Rule 24(2) EPC): DREC	
	Date of receipt at EPO (Rule 24(4) EPC): RENA	
	Date of filing: DFIL	
1	**Request**	
	Grant of a European patent, and examination of the application under Article 94, are hereby requested.	
	Procedural language:	en
2-1	**Applicant 1**	
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	Country of residence:	NL Netherlands
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	Registration No.:	0.0
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	Telephone:	+31 40 2743444
	Fax:	+31 40 2743489
4	**Inventor(s)**	
5	**Title of invention**	
	Title:	Electrical converter for converting electrical power

User reference: PHNL030049EPP
System identification: 37634.6820566551
Application No:

6	**Designation of Contracting States**			
6-1	All states which are contracting states to the EPC at the time of filing of this application are hereby designated.	✓		
6-2	It is requested that no communications under Rules 85a(1) and 69(1) EPC be notified concerning the contracting states not selected under 6.4	✓		
6-3	If an automatic debit order has been issued, the EPO is authorised, on expiry of the basic period under Article 79(2) EPC, to debit seven times the amount of the designation fee if fewer than seven contracting states are indicated, the EPO will debit designation fees only for those states, unless it is instructed to do otherwise before expiry of the basic period	✓		
6-4	The applicant currently intends to pay designation fees for the following states:	AT BE BG CH&LI CY CZ DE DK EE ES FI FR GB GR IE IT LU MC NL PT SE SI SK TR		
6-5	Payment of seven times the amount of the designation fee is deemed to constitute payment of the designation fees for all the contracting states (Article 2, No. 3 RFees).	✓		
7	**Extension of the European patent**			
7-1	This application is deemed to be a request to extend the European patent application and the European patent granted in respect of it to all non-contracting states to the EPC with which extension agreements exist on the date on which the application is filed. However, the extension only takes effect if the prescribed extension fee is paid.	✓		
7-2	The applicant currently intends to pay extension fees for the following states:			
8	**Declaration of priority**			
9	**Deposit of Biological Material** The invention relates to and/or uses biological material which has been deposited under Rule 28 EPC			
10	**Nucleotide and amino acid sequences**			
11	**Forms**	Details:		Electronic File:
11-1	Request			as EPF1001.PDF
11-2	Fee settlement			
11-3	Validation log			
12	**Technical Documents**	Details:		Electronic File:
12-1	Specification	11 claims;figure(s) 1		nl030049.pdf
12-2	Drawings	9 figures		draw.pdf
12-3	Pre-conversion archive			nl030049ae.zip
13	**Other Documents**			
14	**Payment**			
15	**Fees**	Factor applied	Fee schedule	Amount to be paid
	Total:		EUR	0.00

User reference:	PHNL030049EPP
System identification:	37634.6820566551
Application No:	

16	Annotations	

17 Signature(s)

Signed by:	**NL, NL, Philips Internat. BV, G. Hesselmann**
	DE, DE, D-Trust GmbH, D-Trust for EPO 2.0
Capacity:	**Authorised representative (Representative 1)**

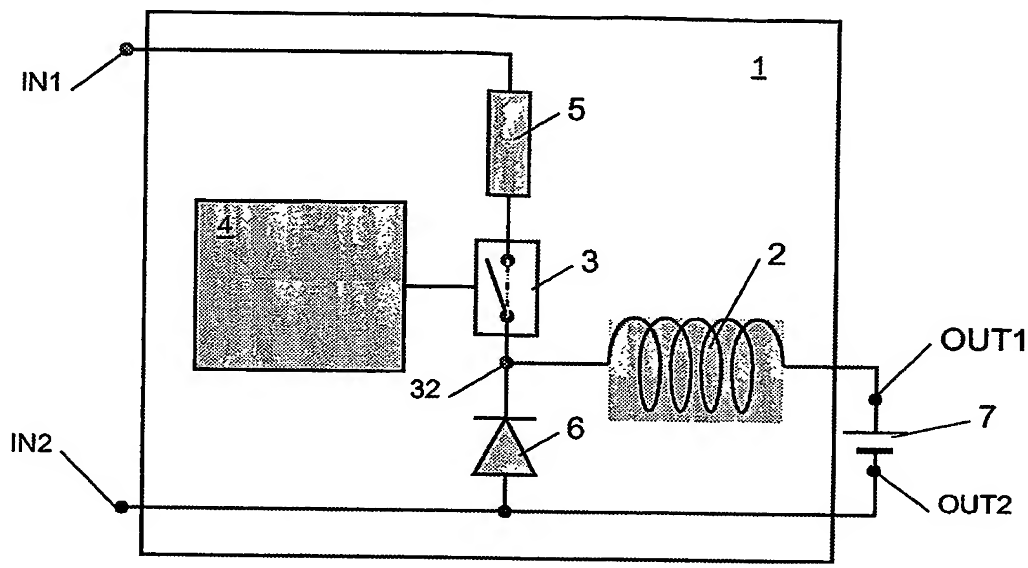


FIG.1

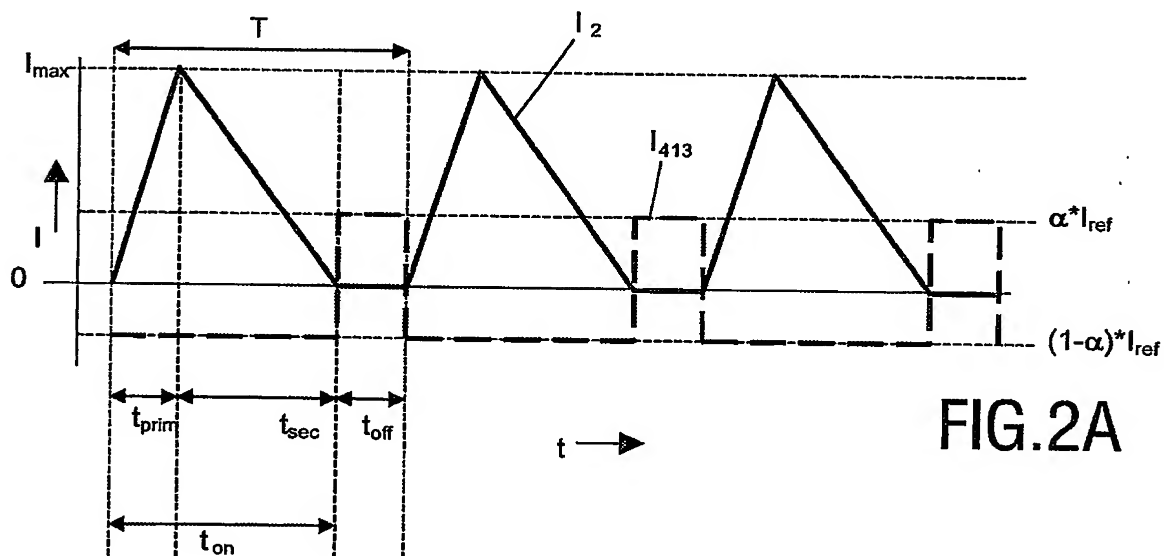


FIG.2A

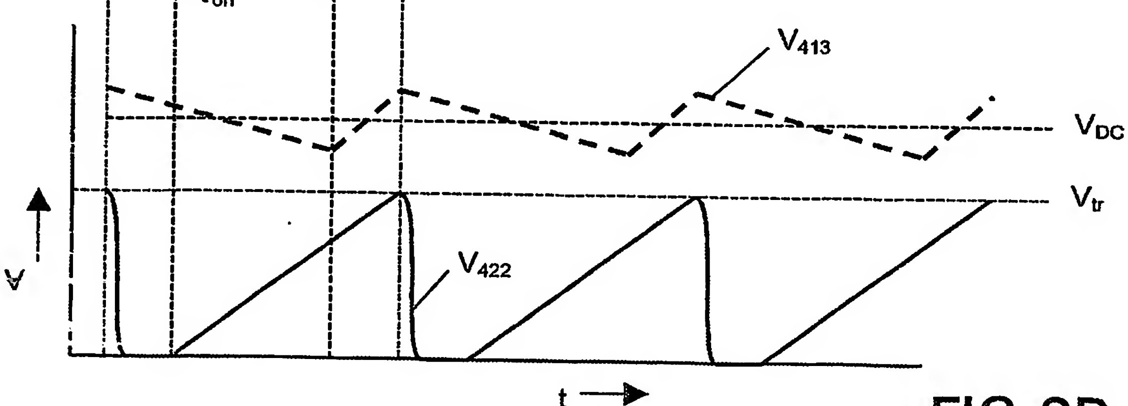
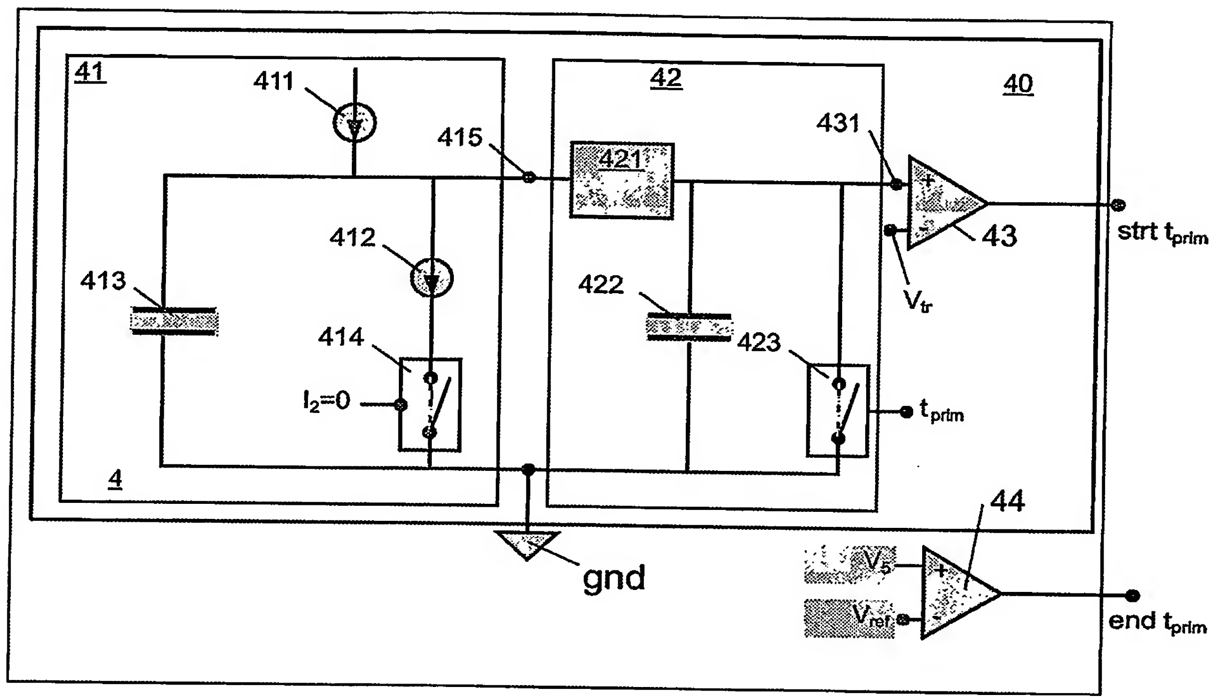


FIG.2B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411
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413
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423
43
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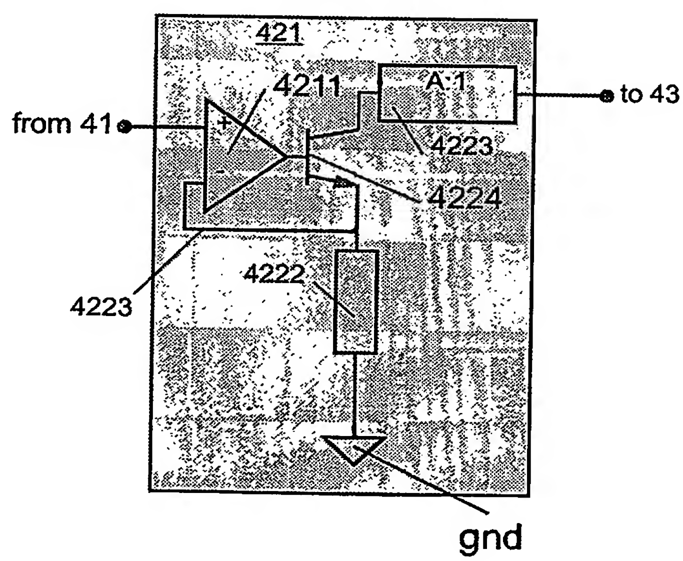
t_{prim}
44
gnd
V_5
V_{ref}
end t_{prim}

FIG.3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A:1
to 43
from 41
4223
4224
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4223
gnd

FIG.4

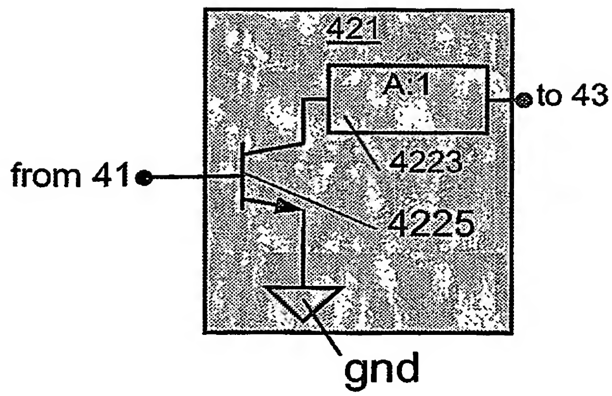

FIG.5

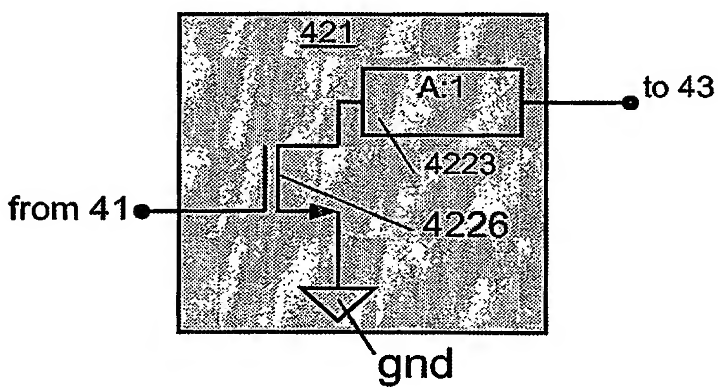

FIG.6

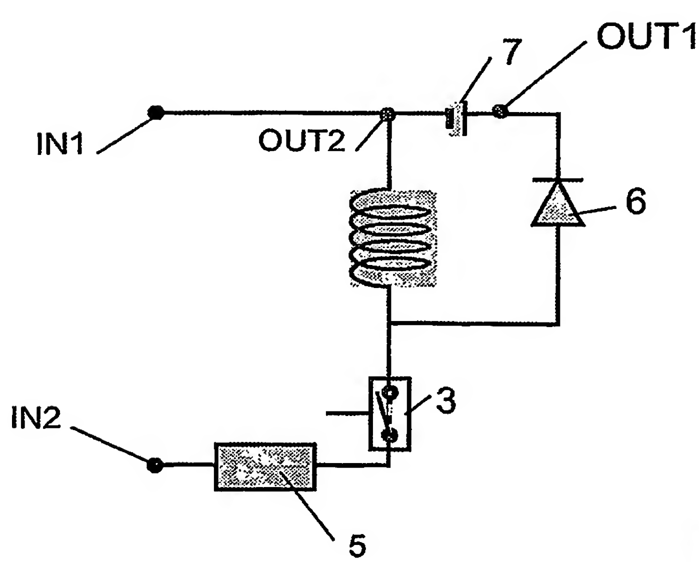

FIG.7

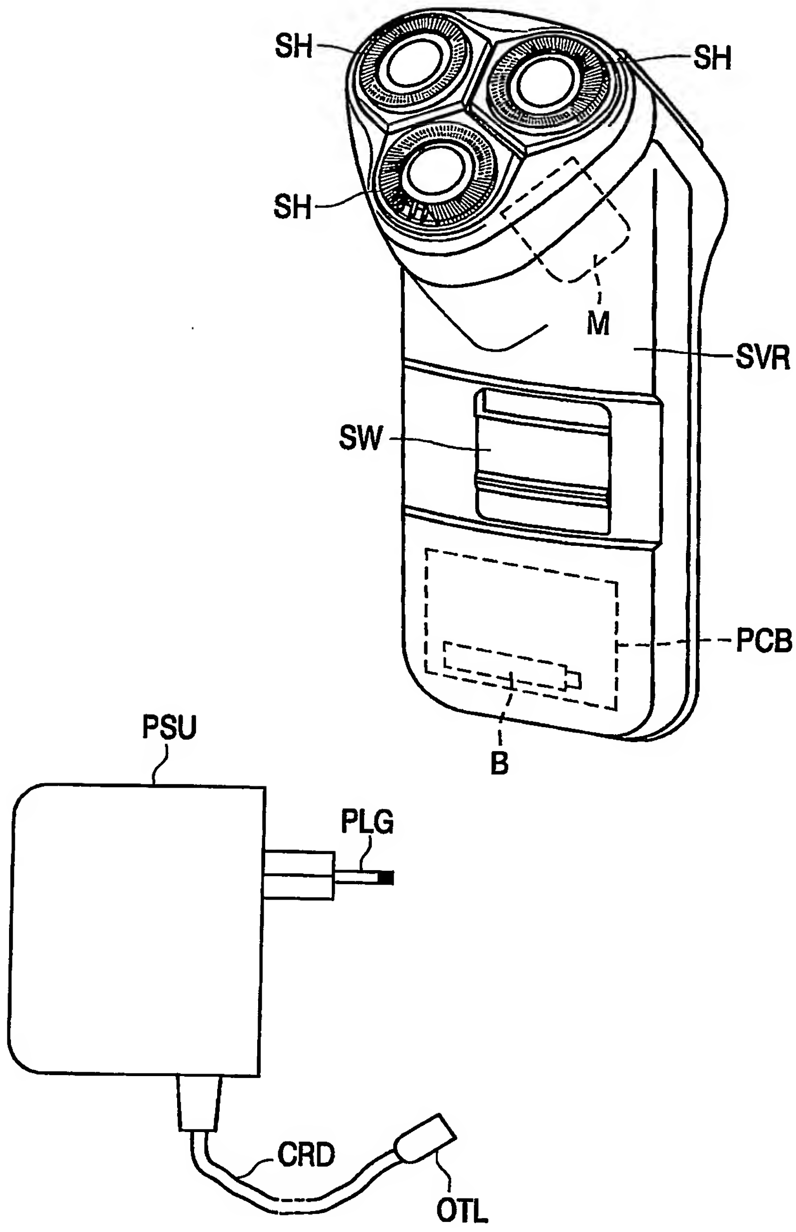

FIG. 8